New SiGe technologies with cut-off frequencies towards 600 GHz and their potential impact on future mmW sensing in automotive and industrial applications

IPCEI on Microelectronics

MIKON-2020

MRW 2020 Microwave and Radar Week

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Infineon

Outline

1. Motivation
2. 130nm BiCMOS technology B11HFC
3. DPSA-SEG vs. Epitaxial Base Link (EBL)
4. Infineon‘s next generation 600GHz technology
5. Impact on future high frequency applications
6. Conclusions

Outline

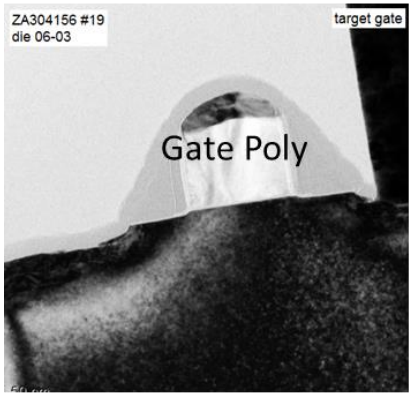
Motivation

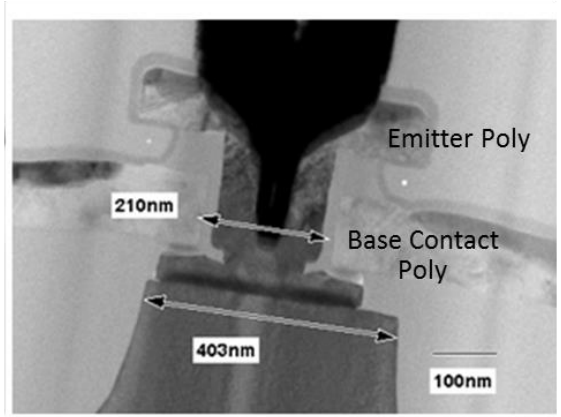
- Advantages of technologies with higher frequencies
  - Improved bandwidth for high speed communication and high resolution radar
  - New solutions at higher frequencies become feasible
  - Lower power consumption
  - Better noise performance

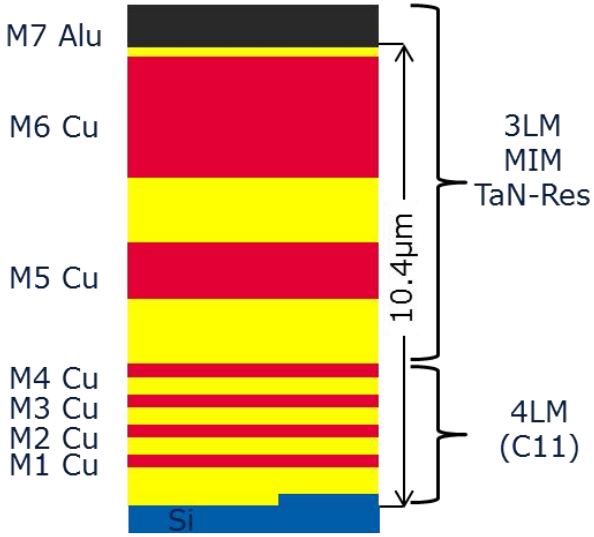
Outline

B11HFC : 130nm BiCMOS

130nm MOSFETs (C11) & Scaled SiGe HBTs DOT5/7 & mmwave BEOL / Passives (B7HF200)



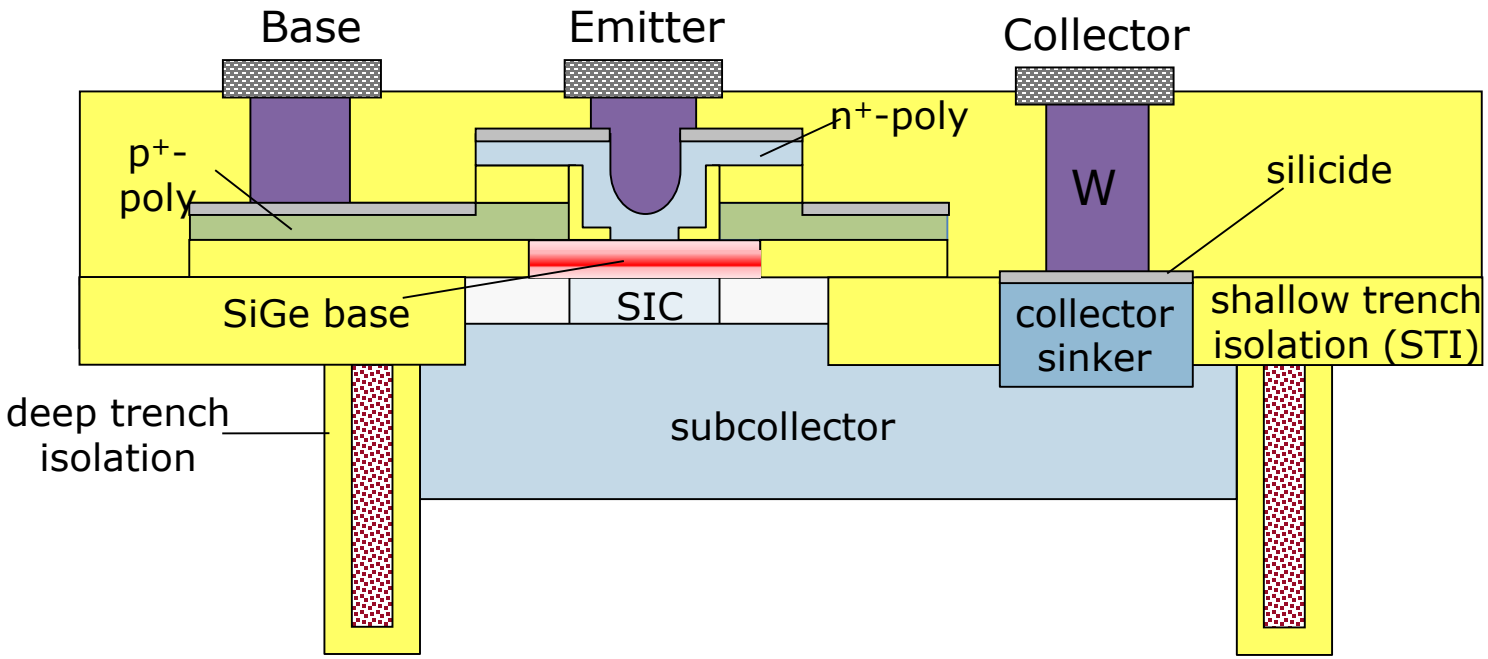




- Mature 130 nm CMOS node
- High-speed SiGe HBTs with f_T = 250GHz , f_{max} = 370GHz
- 7 layer metallization with MIM capacitor, metal resistor and laser fuse
- Qualified in 2017

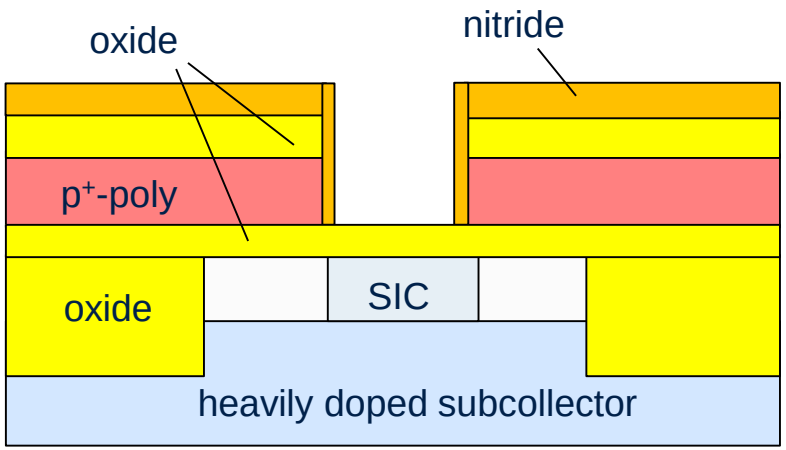
Outline

DPSA configuration of SiGe HBT used in current production

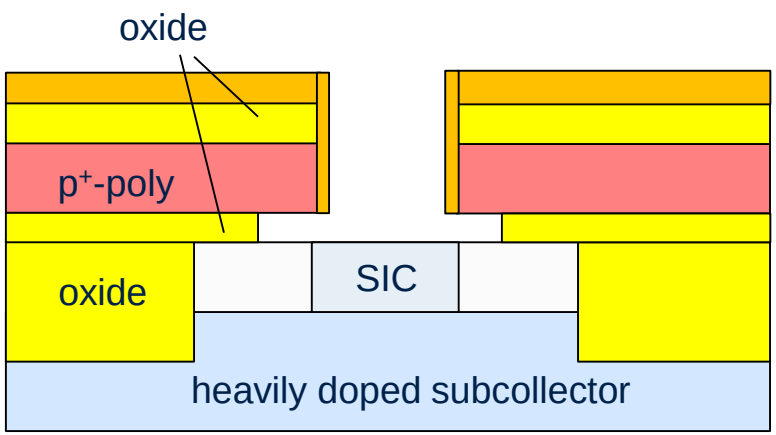


- E/B configuration: Double Polysilicon Self-Aligned with Selectively Grown Epitaxial Base Link (DPSA-SEG)
- Transistor isolation: Deep trench (DT) and shallow trench isolation (STI)

Fabrication DPSA-SEG HBT - 1

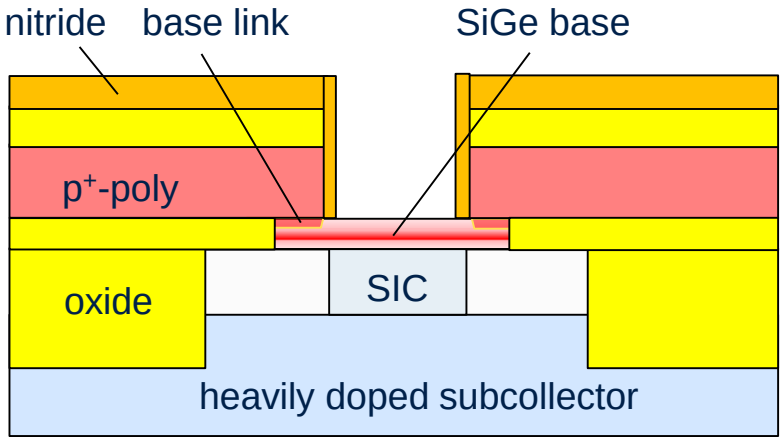


- Deposition of pedestal oxide/p^+-poly/oxide/nitride stack on transistor isolation
- Patterning of emitter window
- Formation of nitride spacers
- Self-aligned collector implantation (SIC)

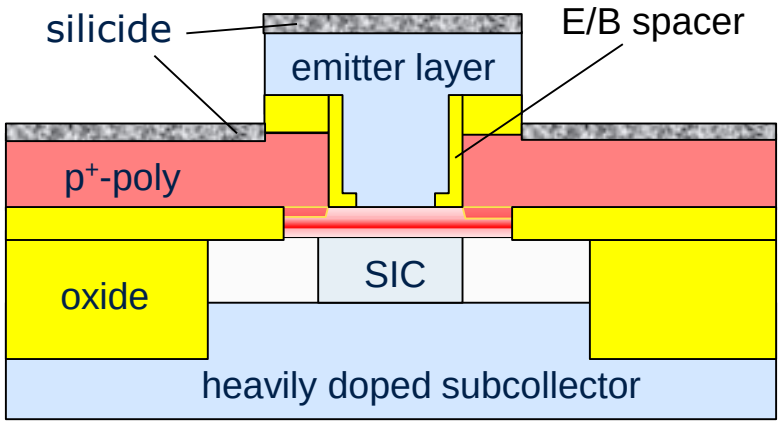


- Wet etch of pedestal oxide ➔ creates self-aligned adjusted p^+-poly overhangs

Fabrication DPSA-SEG HBT - 2



- Selective epitaxial growth of SiGe base
  - Growth only occurs on Si or poly-Si regions not covered by oxide or nitride
  - During SEG the base link is formed which connects the SiGe base with the p^+-poly base electrodes

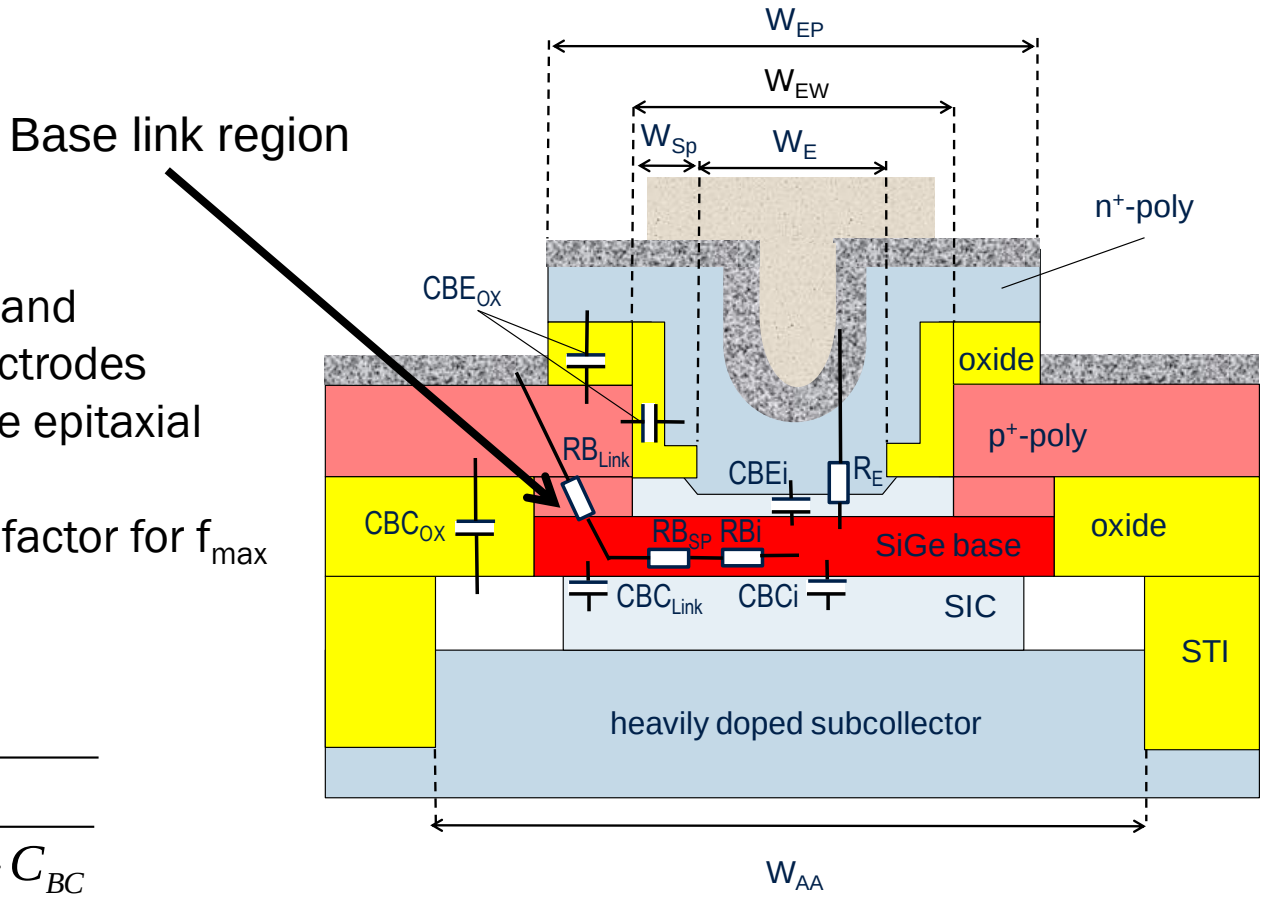


- Nitride layer removal
- Formation of emitter/base spacer
- Emitter deposition
- Emitter patterning
- Silicidation

Base Link Region

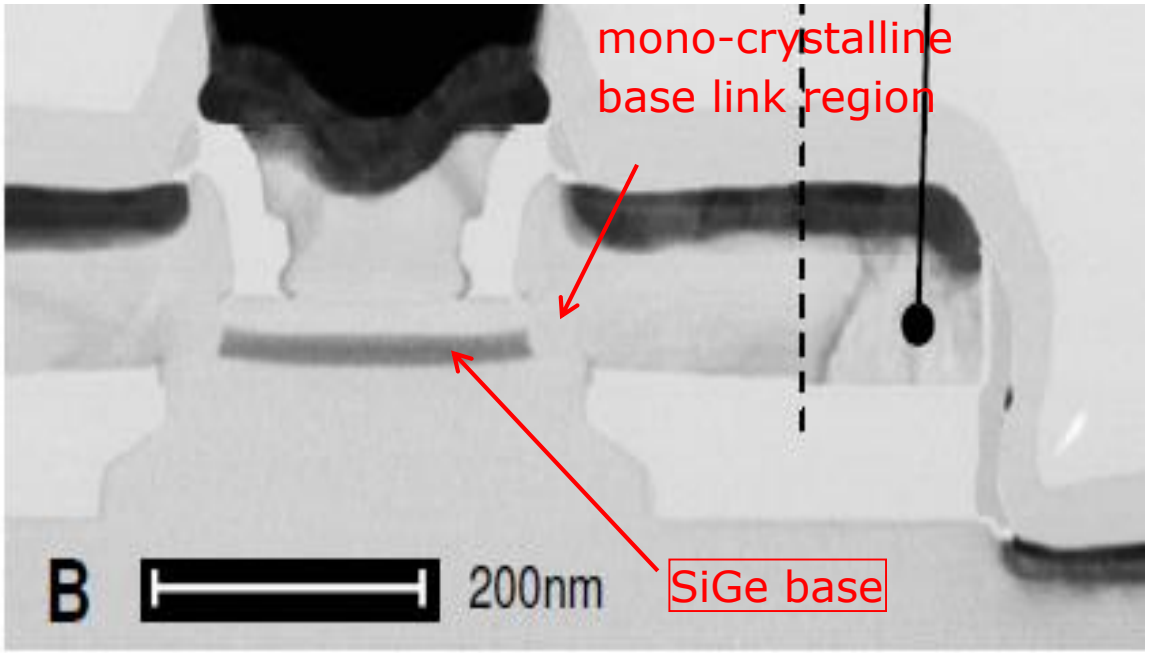
- Links active NPN base and p+-polysilicon base electrodes
- Formed during selective epitaxial growth
- This is a major limiting factor for f_{max} (high RB)

$$f_{\max} \approx \sqrt{\frac{f_T}{8\pi \cdot R_B \cdot C_{BC}}}$$



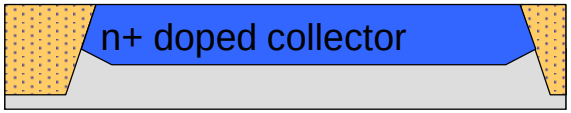
- Schematic cross section of EB region and electrical parasitic elements

HBT with epitaxial grown base link (IHP)

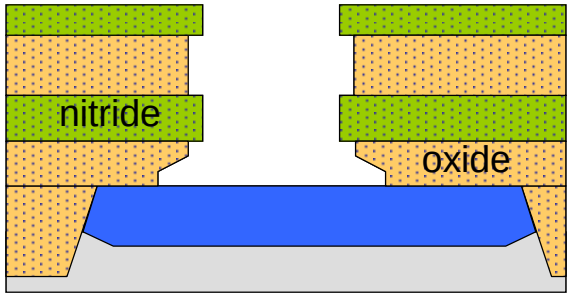


- Basic idea: de-couple SiGe base and base link deposition
- Highly doped base link epitaxy: low R_B
- No base link anneal necessary: steep base profile, high f_T

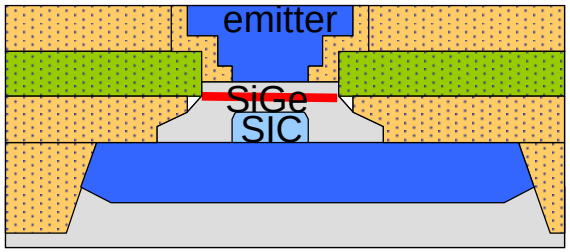
Process Flow for Epitaxial Base Link Module (I)



- Isolation and sub-collector

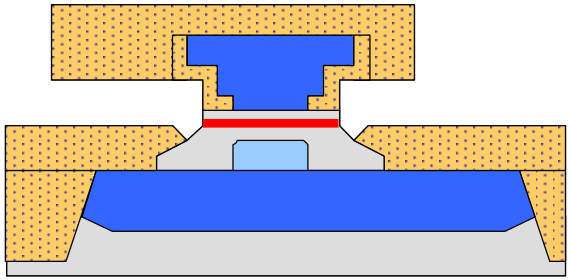


- ONON deposition
- Emitter-window etch

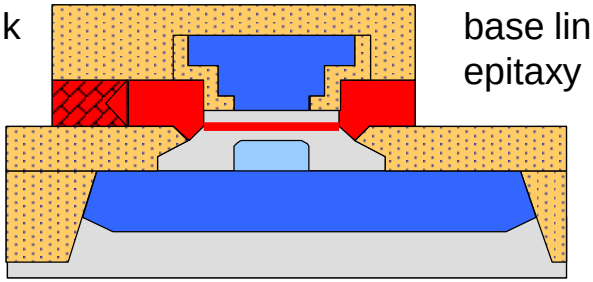


- Selective collector epitaxy
- Collector implant (SIC)
- Selective SiGe base epitaxy
- Emitter-base spacer
- Emitter deposition and CMP

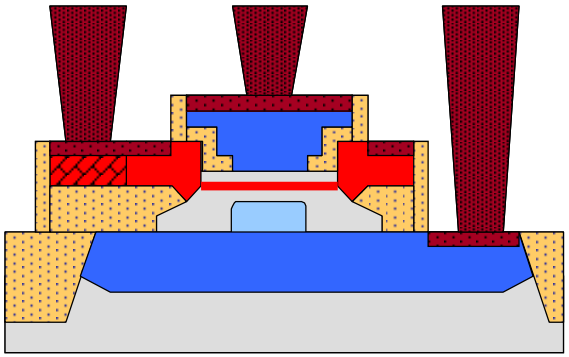
Process Flow for Epitaxial Base Link Module (I)



- Cover oxide deposition and etch
- Dummy nitride strip



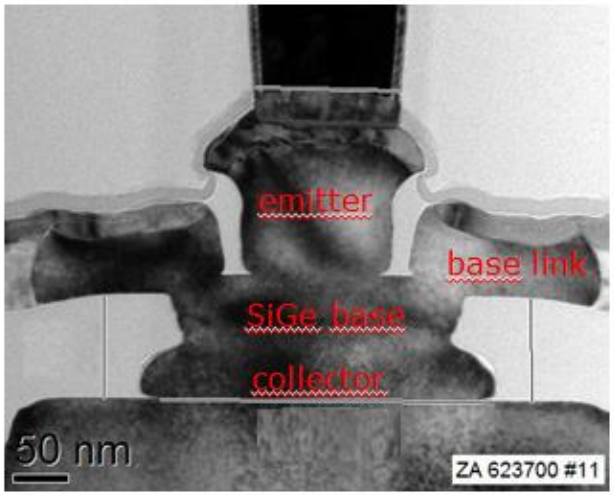
- Selective base link epitaxy
- Poly-crystalline deposition of outer base electrodes
- Base electrode etch

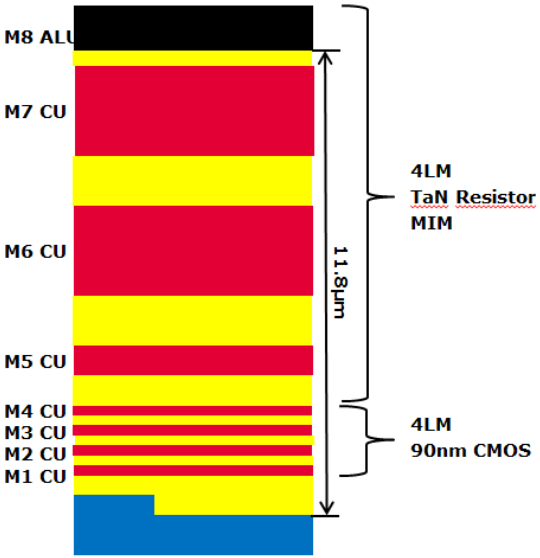


- Salicide
- Contacts

Outline

Infineon‘s next generation 600GHz BiCMOS technology





- SiGe HBT with epitaxial base link
- 90nm CMOS: 1.9nm thin GOX / 5.8nm thick GOX
- Target values f_T = 300GHz, f_{max} = 600GHz, effective emitter window < 100nm
- 8 layer metallization with TaN resistor, MIM

Most important new unit processes

- selective collector epitaxy
- RIE for emitter window
- CMP for emitter structuring
- selective B-doped epitaxy for base link

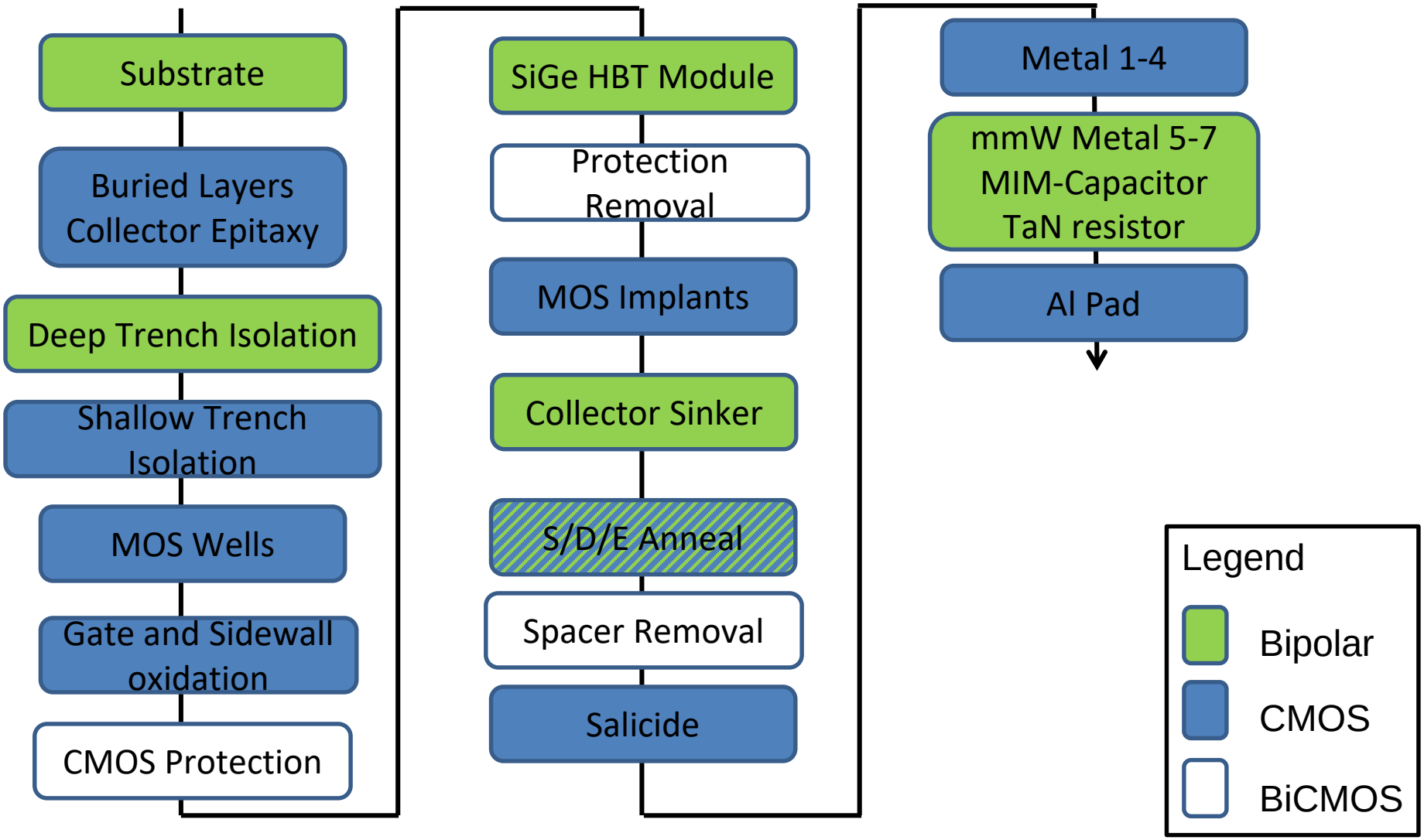
BiCMOS integration issues

- CMOS devices should not be changed (reuse CMOS IP, ROM, SRAM, …)
- MOS thermal steps deteriorate HBT performance
- EBL HBT into Infineon‘s 90nm CMOS technology:
  - Substrate orientation for best HBT performance & yield different from standard CMOS
  - Different optimal thermal budgets for HBT and CMOS fabrication
- Removal of HBT stack from CMOS regions
- Removal of CMOS spacers from bipolar areas

CMOS temperature budget 130nm and 90nm nodes

CMOS node	130nm (B11HFC)	C12 90nm CMOS
STI anneal	1100°C, 80sec	1050°C, 4h
LDD anneal	1010°C spike	1025°C 6.5sec
SD anneal	1050°C spike	1080°C spike

BiCMOS process flow



Integration in 90nm CMOS

- B11HFC like integration scheme can be kept but significant reduction of STI, LDD and S/D anneal necessary

- Re-adjustment of CMOS parameters by :
  - Reduction of offset spacer length before LDD implantation
  - Adjustment of implant conditions

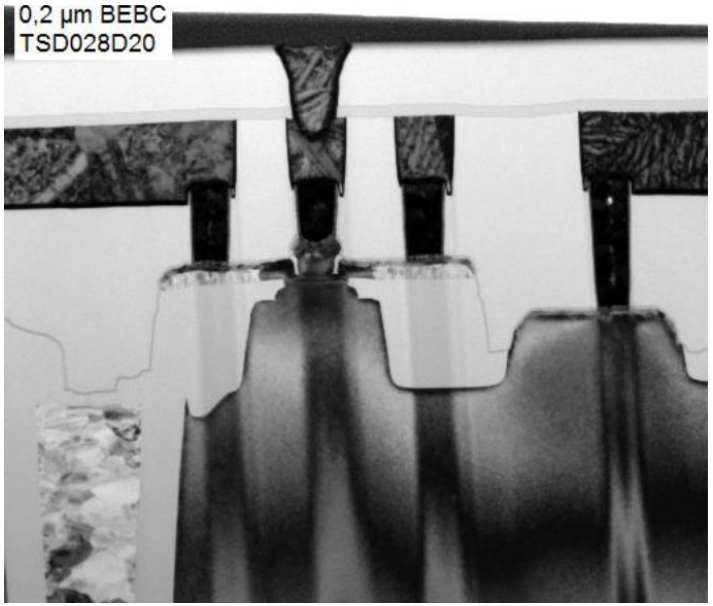
DOTSEVEN : Common processing between IHP and Infineon in 130nm node

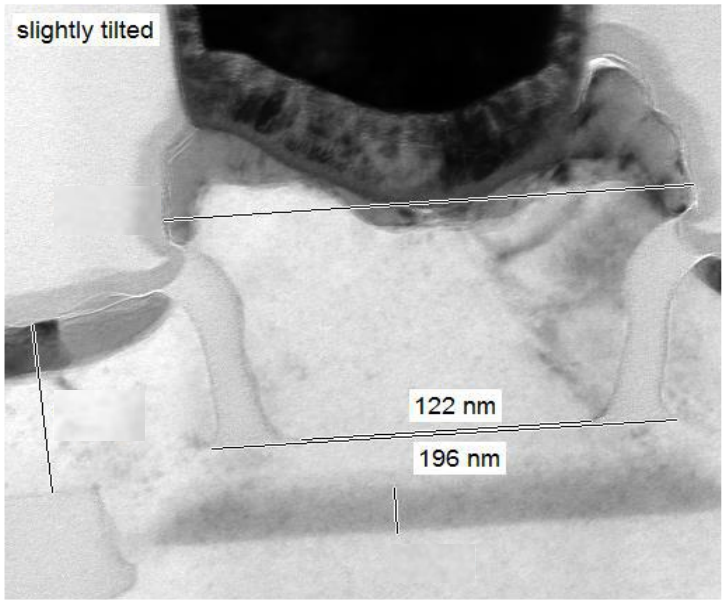
- Buried layers, blanket epitaxy
- Isolation, Wells, Gate
- MOS extension and S/D implants
- S/D anneal
- Salicide, contacts, metalization

- EB stack and etch
- Selective collector epitaxy, SiGe base, EB spacer, emitter, base link

› two learning cycles for assessment of EBL concept capability:
  › joint processing between IHP and Infineon
  › complete processing at Infineon

Cross section of EBL HBT in Infineon‘s 130nm technology

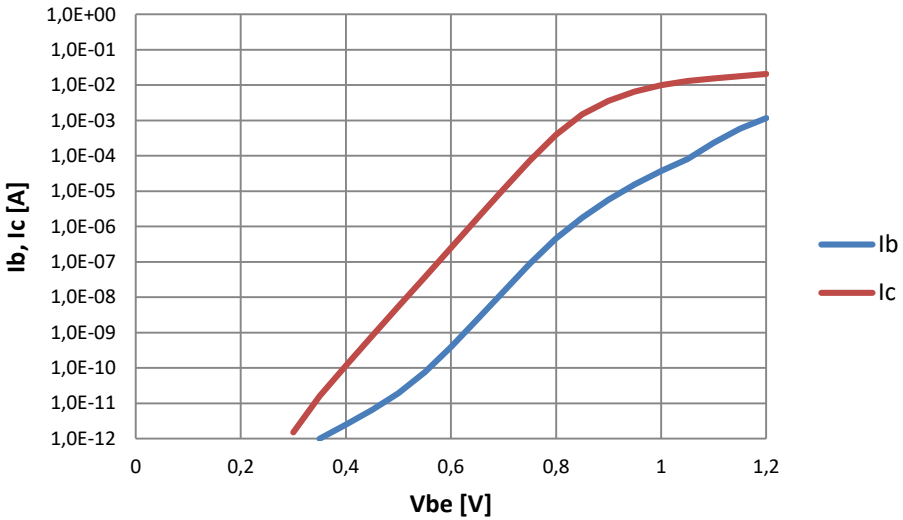




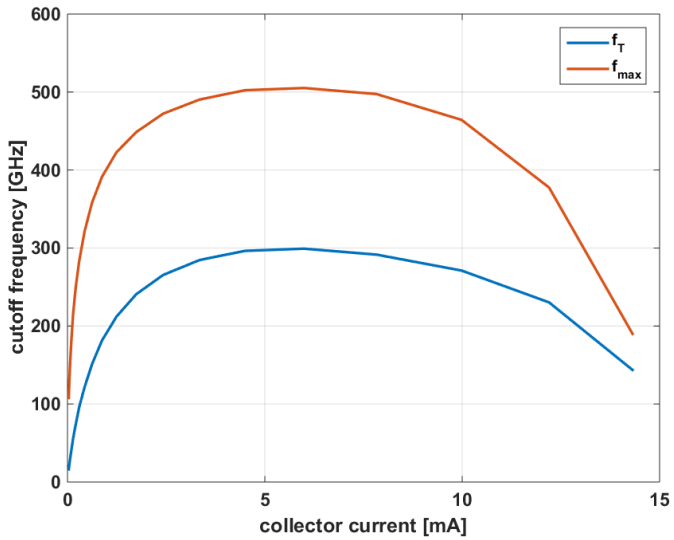
- Complete processing done at Infineon
- 130nm lithography used
- Effective emitter window not yet scaled down significantly

HBT with EBL in Infineon‘s 130nm BiCMOS technology, performance

Gummel Plot



f_T, f_{max} vs. Collector current



Improvements to be made to achieve f_{max} of 600GHz

- Integration in 90nm node :
  - Better lithography tools give access to smaller emitter window and tighter overlay in transistor layout.

  →Lateral shrink will further improve fmax

- Optimization of collector and E/B profile to improve the transit frequency f_T

- Further optimization of base link epitaxy to achieve lower base resistance

Outline

Benfits of new technology for radar applications at f_{op} = 77GHz

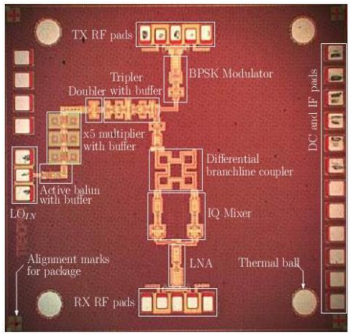
- 130nm → 90nm CMOS
  - Higher integration capability
  - Lower cost

- Better RF performance of SiGe HBT :
  - Lower power consumption at the same functionality or better performance at same power consumption.
  - Higher TX / RX duty cycle
  - More TX / RX functions on chip

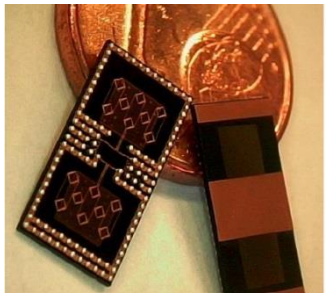
Radar Evolution Beyond 77GHz

- Higher operation frequency → smaller antenna size
- Smaller sensor size → lower cost, better integrability in car

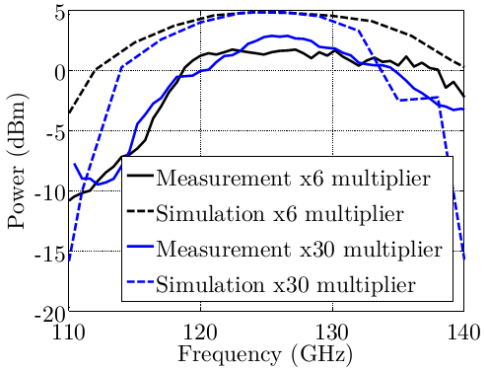
120GHz Transceiver



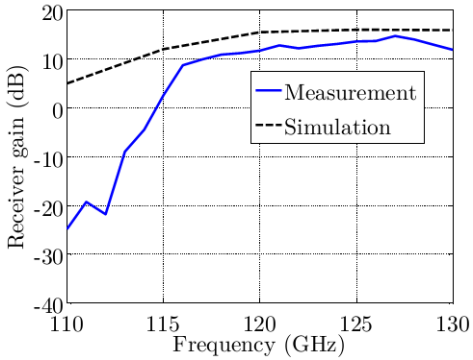
240GHz Antenna Arrays



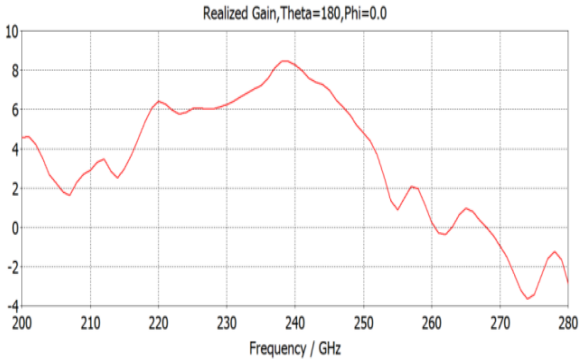
Output Power



Receiver Gain



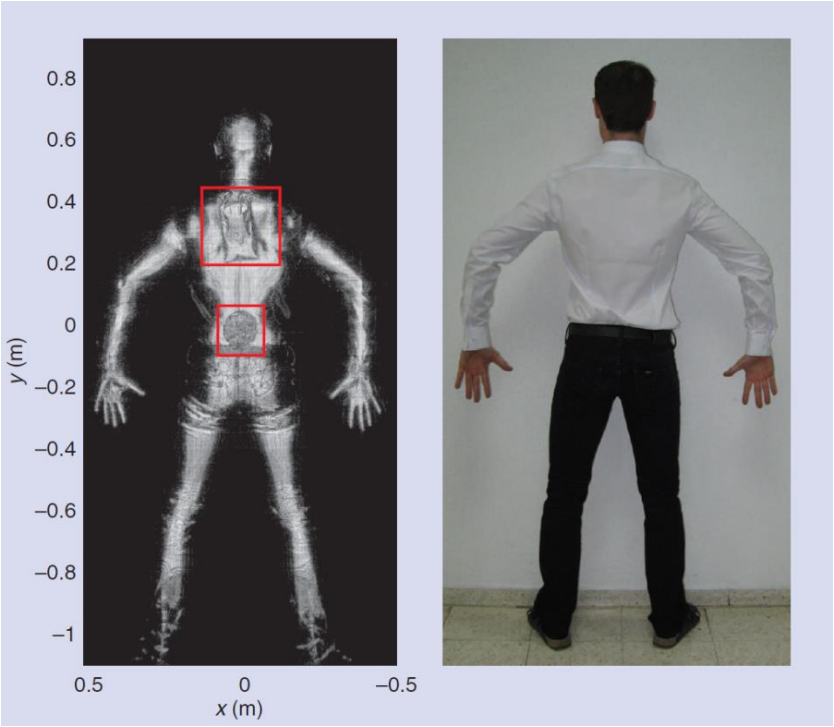
Antenna Gain



Source: DOTSEVEN WP4 (mm-wave circuits and demonstrators)

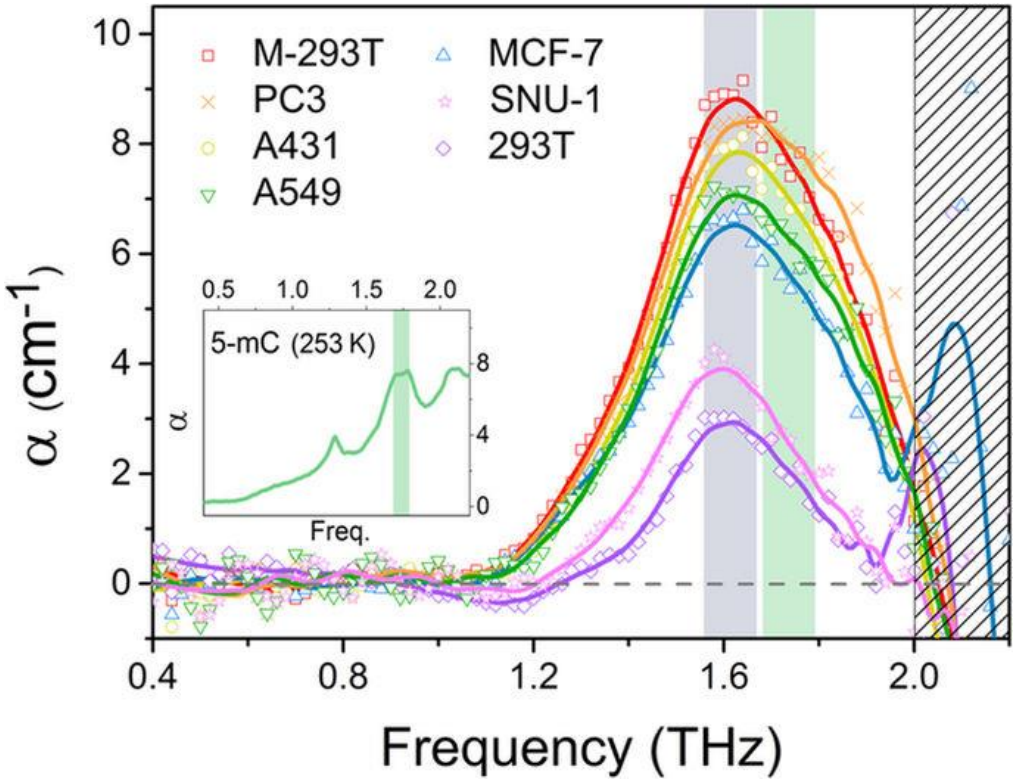
THz Imaging

- Many optically opaque materials are transparent to THz radiation
- Unlike X-Rays THz radiation is non ionizing → Attractive for biomedical sensing and imaging applications
- THz waves exhibit less scattering in comparison to optics and tolerate harsher environmental conditions necessary e.g. for industrial process monitoring



[Source : S.S. Ahmed et al. "Advanced Microwave Imaging" in IEEE Microwave Magazin 13.6 (Sept. 2012)]

THz Spectroscopy – Medical Applications



5 types of cancer DNA:

PC3 - human prostate cancer
A431- human epidermoid carcinoma
A549- alveolar basal epithelial cells
MCF-7- human breast cancer
SNU-1- human gastric cancer

[Source : H.Cheon et al. "Towards Clinical Cancer Cnspection Using Terahertz Spectroscopy" in IEEE Journal of Selected Topics in Quantumelectronics 23.4 (July 2017)]

Outline

Conclusion

- To achieve a maximum oscillation frequency towards 600GHz a new transistor architecture with epitaxial base link is essential
- fT = 300 GHz / fmax = 500GHz achieved with EBL cell in 130nm CMOS. Further performance enhancement expected by lateral shrink and improvement of vertical profiles.
- Integration in 90nm CMOS is feasible by changing MOS temperature budget and reengineering of MOS devices.
- Existing and new applications will benefit from new technology

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